THE BEHAVIOUR OF PARTIALLY CLOGGED GEOTEXTILES UNDER CONFINEMENT

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ABSTRACT: This work presents a study on the influence of different levels of geotextile impregnation by soil particles under confinement. Partial clogging can occur during construction due to soil spreading and compaction on the geotextile layer or throughout the service life of the drainage systems. Specimens, artificially clogged in the laboratory and exhumed from actual field works, were tested to assess their normal and longitudinal coefficient of permeability under different levels of soil impregnation and normal stresses. The microstructure and pore characteristics of partially clogged geotextiles under confinement image analyses were also assessed. The results obtained showed a considerably influence of stress level and partial clogging on the drainage and filter performance. However, the results obtained showed that the in plane geotextile drainage capacity may not be affected by the intrusion of soil particles in the geotextile matrix.

1 INTRODUCTION

Geosynthetics have been extensively used as drains and filters in geotechnical and environmental protection works. Despite the increase of geosynthetic uses in such works, its long term behaviour in major engineering projects such as larger dams and mining waste piles is still of major concern among designers and practitioners. In some of these projects, failure of the draining and filter systems may cause major accidents with serious consequences such as material losses, environmental damages and, even worse, loss of human lives. Besides durability, which is outside the scope of the present work, some of the main concerns raised in the utilization of geosynthetic filters in major engineering projects are the effects of large stress level on the filter/drain behaviour, retention capacity and clogging mechanisms. In the particular case of drainage systems of large waste disposal areas, the variability of the fluid composition, its viscosity, solids in suspension and bacterial activity are additional aggravating components to the system performance and challenges to the designer, as such designs are based on test results performed under controlled laboratory conditions using clean geotextile specimens and fluids.

The need for the study of geosynthetic drainage/filter systems under working conditions have increased, particularly to assess long term behaviour of these materials. In this sense the impregnation, or partial clogging, of a geotextile layer in the field may be caused by spreading and compaction of soil on it during construction or even by the action of seepage forces, carrying loose soil particles from the base soil which are retained in the filter matrix. Figure 1 shows schematically a mechanism of impregnation of a geotextile layer during spreading of soil in the field. The presence of the soil particles in the geotextile voids will influence its normal and in-plane permeability values, as well as it pore spaces and constriction sizes, with repercussion to retention capacity and clogging potential.

This paper presents an investigation on the effects of soil particles intrusions in the geotextile matrix on the physical, hydraulic and filter characteristics of partially clogged geotextile specimens under laboratory and field conditions and subjected to testing under high normal stress levels.

2 TESTING PROGRAMME

2.1 *Apparatus used in the testing programme*

Permittivity and transmissivity tests were performed to evaluate the behaviour of partially clogged geotextiles under normal stresses up to 2000 kPa. The equipment employed for the transmissivity tests under such high normal stresses was based on the one presented in ASTM D4716 (ASTM, 1993) and is schematically shown in Figure 2.

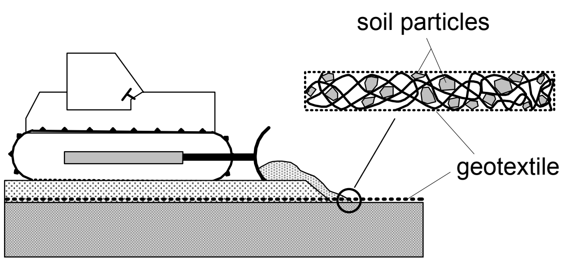


Figure 1. Geotextile impregnation by soil particles during spreading and compaction of a fill layer.

The geotextile specimen (100 x 100 mm) is subjected to the normal stresses applied by a rigid platen provided with special sealing, to avoid undesired preferential flows through gaps and interfaces. An hydraulic system allows the application of the normal load, which is measured by a load cell.

The variations of geotextile thickness were obtained from the average vertical movements of the loading platen, measured by displacement transducers installed at three different positions on the platen. Four piezometers (spacing equal to 20mm) were installed at the base of the testing cell, allowing to assess the variations of hydraulic heads along the geotextile length. These measurements may be useful to identify clogging mechanisms along the geotextile specimen length. (Gardoni and Palmeira 1999).

The permittivity tests were conducted using a equipment developed at the Ecole Polytechnique, Montreal, Quebec, Canadá (Figure 3a), designed based on the similar according to ASTM D 5493 (ASTM, 1993). The equipment is composed by a permeameter cell, a deaired water supply system, a hydraulic system for load applications, yielding to normal stresses ranging from 20 to 1000 kPa. The permeameter is made of stainless steel, with 50.8 mm diameter and 280 mm high.

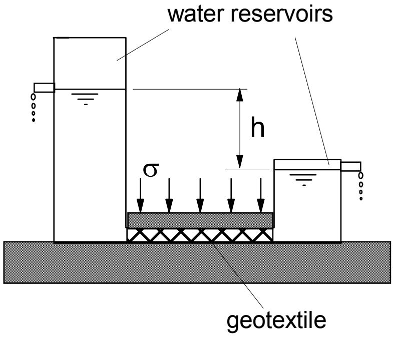
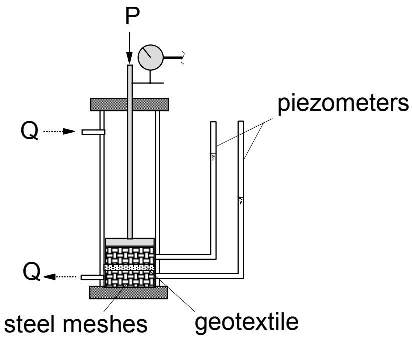
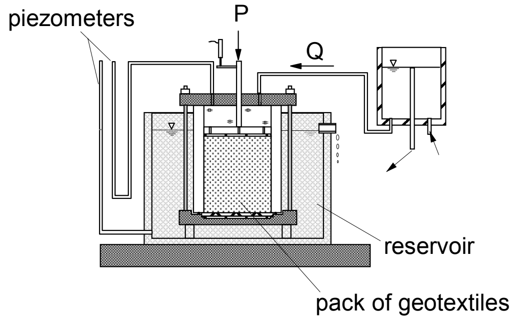


Figure 2 Apparatus for geotextile specimen transmissivity tests.

A second permeameter developed at the University of British Columbia was also employed in the test programme. This permeameter is presented in Figure 3b. In this permeameter packs of geotextiles were tested, rather than single layers of specimens. The permeameter cell is made of aluminium, 125 mm high, and the geotextile specimens have a diameter of 102 mm. Further information on this equipment can be found in Fannin et al. (1996) and Palmeira et al. (1996).



(a) Equipment for testing individual layers of geotextiles



(b) Equipment for testing packs of geotextile layers

Figure 3 Apparatus used for permittivity tests.

The dimensions of the soil particles that impregnated the geotextile fabric matrix were obtained by an automatic image analyser manufactured by Clemex Technology Incorporation (Longueil, Quebec, Canadá). The equipment consists of a Nikon microscope with a Sony RGB photographic camera and a data acquisition system. Additional information on this equipment and technique employed can be obtained in Forget and Goldman (1998), Clemex (1999) e Gardoni (2000).

2.2 *Materials and methodology employed*

Eight types of nonwoven geotextiles were used in the tests on partially clogged geotextile specimens (Table 1). These geotextiles are needle-punched, and will be referred hereafter as geotextiles GA to GH. Geotextiles GA to GE (from manufacturer 1) are made of continuous monofilaments of polyester. Geotextile GF (from manufacturer 2) is also made of polyester and needle punched. Geotextiles GG and GH are nonwovens made of polypropelene. The main characteristics of the products tested are presented in Table 1. The diameters of the fibers of the geotextiles were measured by microscopy.

Table 1 Geotextile characteristics

Geotextile	$M_A{}^{(2)}$ (g/m^2)	$t_{GT}{}^{(3)}$ (mm)	$n^{(4)}$	$K_n{}^{(5)}$ (cm/s)	$\psi^{(6)}$ (s^{-1})	$O_S{}^{(7)}$ (μm)	$d_f{}^{(8)}$ (μm)
GA	140	2.2	0.94	0.40	2.1	140	27
GB	200	2.3	0.93	0.40	1.9	130	27
GC	300	3.4	0.93	0.40	1.5	110	27
GD	400	3.7	0.92	0.40	1.1	90	27
GE	600	4.6	0.90	0.40	0.9	60	27
GF	222	2,3	0,92	-	-	60	26
GG	300	2,8	0,88	-	1,5	150	28
GH	130	1,4	0,90	0,40	2,9	200-500	37

Notes: $^{(1)}$ Geotextile code, $^{(2)}$ M_A = mass per unit area (ASTM D3776); $^{(3)}$ t_{GT} = geotextile thickness; $^{(4)}$ n = geotextile porosity; $^{(5)}$ k_n = permeability normal to the geotextile plane (AFNOR NF G 38016); $^{(6)}$ ψ = geotextile permittivity (AFNOR NFG38016); $^{(7)}$ Filtration Opening Size (AFNOR NF G 38017), $^{(8)}$ fiber diameter.

The choice of the specimens of each product to be tested was made by mapping the product layer and using a table of random numbers. A statistical technique associating the number of specimens to be tested to a target level of acceptable error was employed in order to establish a minimum number of specimens of each product to be tested (Gardoni, 2000). This yielded a minimum number of 7 tests for each product.

The geotextile specimens were previously saturated with deaired water and subjected to vacuum for a period of two hours to guarantee total removal of air from the voids.

Placement of the specimens and equipment assembling were made under submerged conditions, to maintain the saturation of the geotextile specimens.

The impregnation of the geotextiles by soil particles for the permittivity and transmissivity tests was made under field and laboratory conditions, using five types of soils. Figures 4 (a) and (b) show the grain size distribution curves of the soils used, where it can be noted a wide range of dimensions of soil particles used in the tests. A residual soil from quartzite (soil SA, in Table 2, a sand (soil B), a clayey soil (soil C) and two types of glass beads where employed to partially clogg the geotextiles. The residual soil is very common in the region of the Federal District, Brazil, and several problems of clogging of granular filter have been reported by the local state highway agency (Gardoni, 1995, Gardoni and Palmeira, 1998). A certain quantity of this soil was collected close or in contact with a nonwoven geotextile filter (400m long) in the BR-020 highway, close to the city of Brasilia, Brazil.

Soil B was collected from a geotextile reinforced retaining wall (Mucambo, state of Bahia, Brazil) built in the Linha Verde highway (Palmeira and Fahel, 2000). The clayey soil (soil C) was collected from the shallow deposit of porous clay that covers great part of the city of Brasilia, Brazil. The two types of glass beads are industrialized materials and were used as reference to verify the accuracy of theoretical solutions that assume spherical shape for the soil particles.

Table 2. Characteristics of the soils used.

Soil Code	Soil Type (1)	D_{10} (2) (mm)	D_{50} (mm)	D_{85} (mm)	CU (3)
SA	RSQ	0.016	0.11	0.2	9.4
SB	Sand	0.053	0.42	0.61	11.5
SC	CS	0.010	0.026	0.20	5.9
SD	GB1	0.062	0.22	0.36	3.7
SE	GB2	0.055	0.17	0.46	4.6
SF	GB3	0.089	0.11	0.18	1.4
SG	GB4	0.054	0.12	0.14	2.2

Notes: (1)RSQ = Residual soil from quartzite collected from the BR-020 highway geotextile drainage system, Sand = sand collected from the backfill of the Mucambo geotextile reinforced wall, CS = clayey soil, GB1 = glass beads 1, GB2 = glass beads 2, GB3 = glass beads 3, GB4 = glass beads 4; (2)Diameter of the soil particle corresponding to 10%, in weight, passing; (3)CU = coefficient of uniformity (= D_{60}/D_{10}).

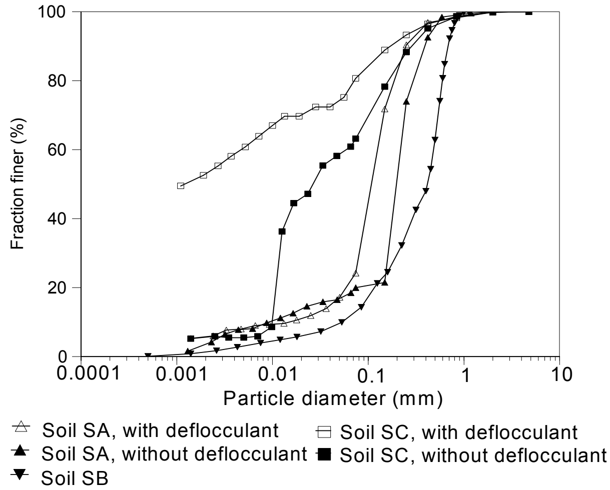
In Figure 4 (b) two grain size curves are presented for the fine grained soils (soils SA and SC), which correspond to grain size analysis sedimentation tests with and without the use of dispersing agent. For these soils, without the use of the dispersing agent, clusters of fine particles are retained by the filter, rather than the individual particles of the clusters, as would be expected also to occur in the field (Gardoni e Palmeira, 1998). However, concerns exist regarding the possibility of the dispersion of these particles from the clusters under continuous and long term flow conditions in the field. This migh lead to further impregnation of the filter by the loosened particles carrried by the flow.

Under laboratory conditions the geotextile specimens were impregnated by glass beads using vibration. For the impregnation of geotextiles by fine grained soils, two different processes were used. The first process consisted in compacting the soil on the geotextile using standard compaction molds, normal Proctor compaction energy and optimum moisture content under laboratory conditions. The second process consisted in the use of test sections in the field where soil SC was spread and compacted on the geotextile layers (2m x 1m) using compaction rolls. In the field, the soil in the test sections was compacted under similar compaction energy as that used in the laboratory tests and under optimum moisture content conditions. After compaction, the geotextile layers were carefully exhumed for further testing and investigations in the laboratory.

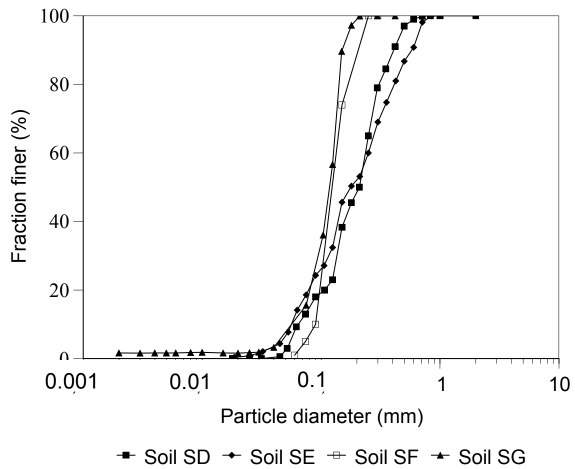
3 TESTS RESULTS

3.1 *Results of Permittivity Tests*

Prior to the tests with partially clogged geotextile specimens, a series of tests with virgin specimens was carried out to serve as references for comparisons. Figures 5 and 6 show the results of tests with virgin specimens in terms of variations of geotextile thickness (t_{GT}) and normal permeability (k_n) versus normal stress. As expected, a significant dependence of t_{GT} and k_n on the normal stress can be observed, particularly for normal stresses below 50 kPa. The geotextile thickness for the products tested become rather constant for normal stresses in the range 800 to 2000 kPa (Fig. 5).



(a) Soils SA, SB and SC



(b) Soils SD to SG

Figure 4 Grain size distribution curves for the soils used.

Figure 6 shows that lighter geotextiles tend to present higher values of normal permeability and for the same manufacturer the value of k_n reduces with the increase of geotextile mass per unit area. It is important to note that products with the similar values of mass per unit area from different manufacturers (geotextiles GC and GG, for instance) may present significant variations of coefficient of permeability. This emphasises the importance of geotextile microstructure on its hydraulic behaviour. (Gourc, 1982, Faure et al., 1982, Palmeira et al., 1996, Gardoni, 2000, Palmeira and Gardoni, 2000 e Gardoni and Palmeira, 2002).

One of the effects of partial clogging on nonwoven geotextile mechanical behaviour is to reduce its compressibility. Figure 7 shows the results of variations of normalised geotextile thickness with normal stress for different levels (λ) of soil particle impregnation for tests with partially clogged specimens of geotextile GA. In this figure the geotextile thickness was normalised by its thickness value at 2kPa normal stress.

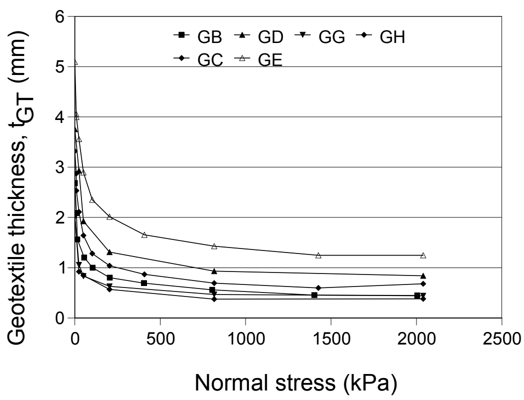


Figure 5. Average geotextile thickness versus normal stress

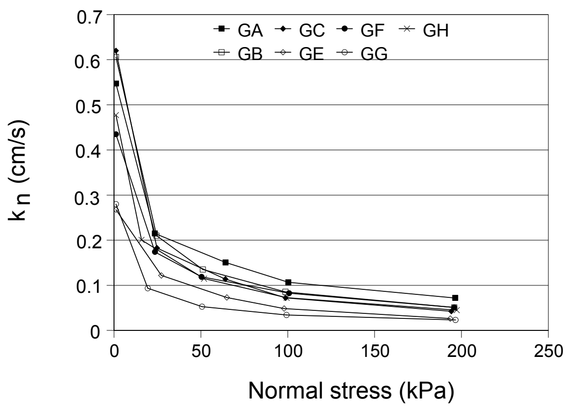


Figure 6. Normal permeability versus normal stress.

The level of impregnation λ is defined as the mass of soil particles inside the geotextile voids divided by the mass of geotextile fibers. A significant reduction of the nonwoven geotextile deformability with normal stress can be noted due to the presence of soil particles in the geotextile voids, suggesting that under field conditions reductions in geotextile thickness can be significantly smaller than those obtained in the laboratory for virgin specimens.

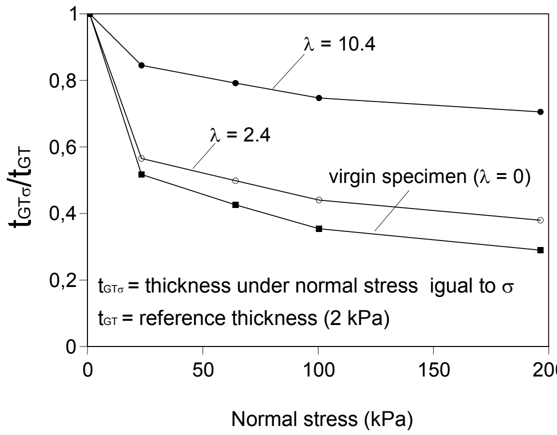


Figure 7. Compressibility of geotextile GA specimens impregnated with soil SG (glass beads).

The values of normal permeability of the partially clogged geotextile is also significantly affected by the presence of soil particles in its voids, as depicted in Figure 8 for geotextile GA. The results in this figure show that the greater the value of λ the greater the reduction of geotextile permeability. The results also suggest that reduction factors to account for loss of permeability caused by particles intrusion should lie in the range 2 to 5, depending on the value of λ and on the stress level.

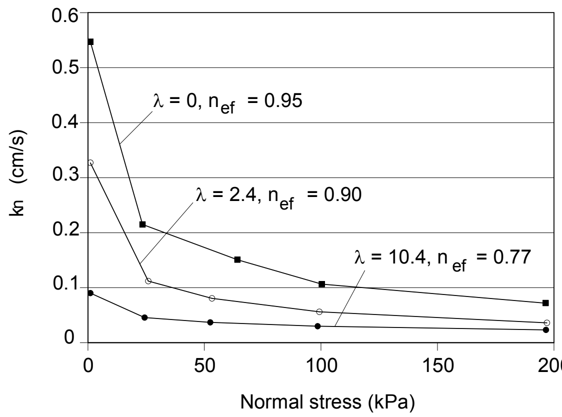


Figure 8. Normal geotextile permeability versus normal stress for different levels of soil impregnation (Geotextile GA, Soil SSG).

3.2 *Results of Transmissivity Tests*

The results of transmissivity tests on virgin specimens are presented in Figure 9 for tests under normal stresses up to 2000 kPa. A significant scatter of results can be observed, even for similar geotextile products. Due care should be taken in extrapolating test results based only on similarity of geotextile products. Depending on the product, even for the same geotextie, a significant scatter of test results can be obtained, particularly for those with low values of mass per unit area (say, below 300 g/m^2, for instance), and also depending on the manufacturing process employed. This is caused because such products may show significant non-uniform distributions of fibers throughout their planes, with concentration of fibers in some regions and rather sparse distributions of fibers in others. These aspects certainly have repercussion not only on hydraulic properties, but also on filter behaviour. Therefore, strict measures of quality control and engineering judgement should be exercised when using such products in severe applications. Further discussions on these aspects can be found in Gardoni e Palmeira (1999).

Figure 9 shows that geotextile transmissivity of virgin geotextiles can be reduced by a factor of 2 to 600 for normal stresses between 0 and 2000 kPa. Such high stress levels can be found even in moderate height mining waste piles, depending on the waste unit weight, for instance.

The influence of the presence of soil particles in the geotextile voids can be assessed by the test results presented in Figure 10. In this figure the range of test results for virgin geotextiles is also presented for comparison. As expected, geotextile transmissivity reduces with the increase of normal stress. However, the results obtained for partially clogged specimens are of the same magnitude observed for the virgin ones or even higher, for the cases of over impregnation of the geotextile. It is important to notice also in Figure 10 that some of the test results were obtained for specimens compacted under actual field conditions. The explanation for the little influence of particle intrusions on geotextile transmissivity is that the presence of the particles causes smaller reductions of geotextile thickness than those that would be obtained for virgin specimens under the same stress level, which affects directly the value of geotextile transmissivity.

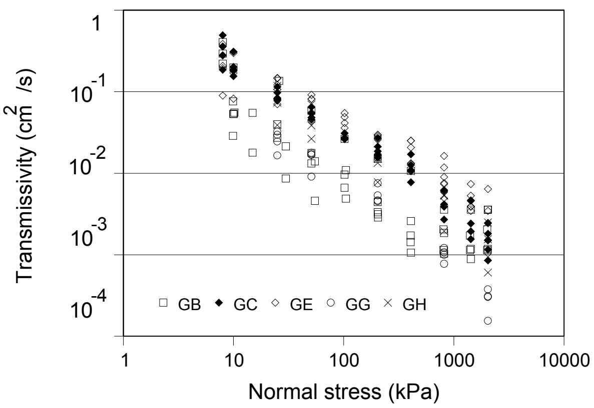
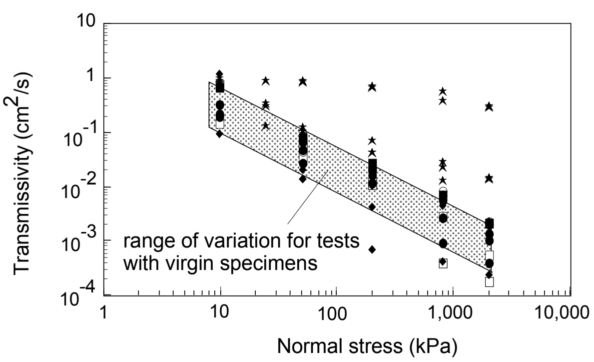


Figura 9. Transmissivity tests results for all virgin specimens.



Geotextile-Soil-Condition:

□ GB-SC-compacted in the field ♦ GB-SC-compacted in the laboratory

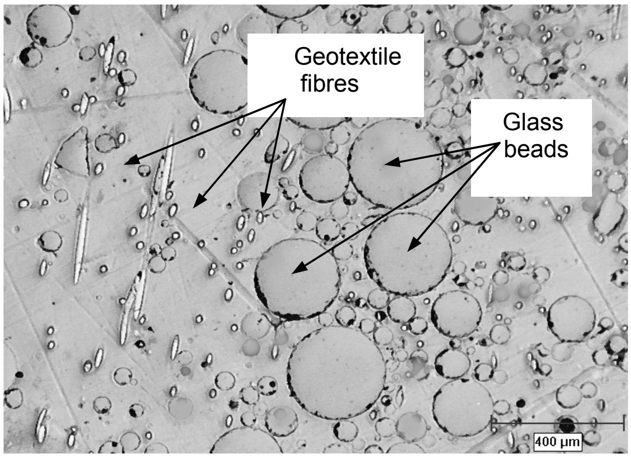
■ GC-SC-compacted in the field ★ GE-SD and SE-vibration in the laboratory

● GE-SC-compacted in the field

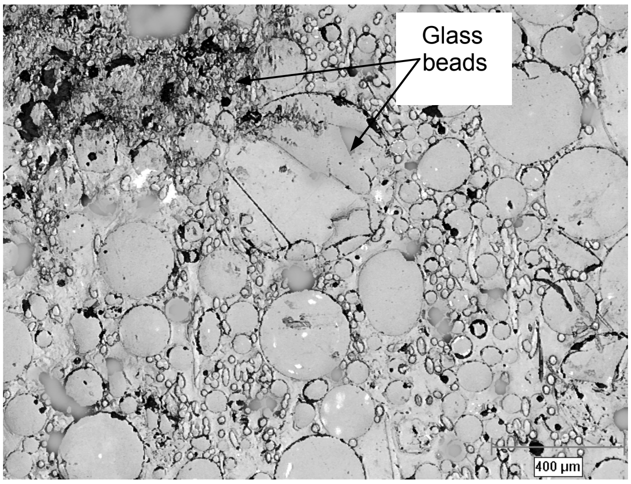
Figure 10. Geotextile transmissivity versus normal stress for partially clogged geotextile specimens.

3.3 *Microscopic Investigations*

Figures 11(a) and (b) show typical microscopic views of specimens of geotextile GA impregnated with glass beads (λ = 12), under 2 and 1000 kPa normal stress respectively. These photographs show that under very low stress levels (Fig. 11a) significant void spaces are still available between the geotextile fibers and the particles. As the stress level increases (Fig. 11b), the volumes of voids are reduced and the compression of the solid matrix (fibers and particles) will be responsible for the changes in geotextile thickness. This explains the significant reduction of the rate of thickness reduction with normal stress in Figure 7 as the stress level increases. The reduction of void space will certainly affect the retention capacity and conditions for clogging of the geotextile filter.



(a) 2 kPa



(b) 1000 kPa

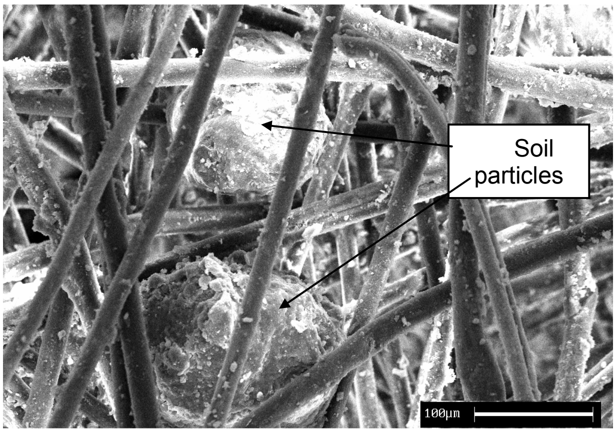
Figure 11. Partially clogged geotextile GA under different normal stresses ((λ = 12).

Figures 12 (a) and (b) show microscopic views of soil particles entrapped in geotextile specimens exhumed from the BR-020 highway drain, as described above. This drain is installed in a residual soil deposit from quartzite. Figure 12(a) shows that considerably large soil particles can intrude in the geotextile voids, compared to the geotextile fiber diameter and void dimensions. Bridges of soil particles and clusters between geotextile fibers can be visualized in Figure 12(b). One should bear in mind that the intrusion mechanism and soil particles arrangements shown in these figure occurred under actual field conditions.

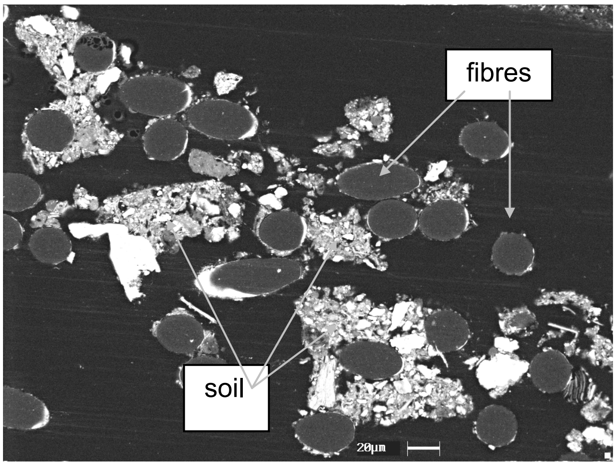
4 CONCLUSIONS

This paper presented a study on the influence of partial clogging of nonwoven geotextiles on their physical and hydraulic behaviour. Geotextile specimens were impregnated with different quantities of soil particles and subjected to compressibility, permittivity and transmissivity tests. The main conclusions obtained in this study are presented below.

Normal and longitudinal permeability values of nonwoven geotextiles are directly dependent on the geotextile characteristics, particularly its microstructure, and stress level. The presence of soil particles in the geotextile voids reduces its compressibility and permittivity. However, little or no effect was observed on the transmissivity of the partially clogged specimens tested when compared to the values of tests on virgin specimens under the same stress levels. This behaviour was due to the reduction of geotextile compressibility because of the soil particles in the geotextile voids.



(a) large individual soil particle.



(b) bridges of soil particles

Figure 12. Soil particle entrapped in exhumed specimens of geotextiles.

The presence of the entrapped soil particles also reduces the voids dimensions, which increases the retention capacity of the geotextile. Therefore, clogging of the geotextile will then be controlled by the remaining pore space between particles and fibers. The combination of partial clogging and confinement will increase even further the retention capacity of the geotextile. These mechanisms are still not approached by current retention and clogging criteria.

Geotextile specimens exhumed from real works showed different levels of partial clogging, similar or greater to those obtained artificially under laboratory conditions. The highest levels of partial clogging in the field were observed in a few cases, where geotextiles were in contact with sandy soils. Soil particles with diameters considerably greater than the fiber diameter could be identified.

The results of the present study emphasizes the need for further investigation on long term behaviour of geotextile filters and their performances under conditions as close as possible to those found in the field.

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